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EFFECT OF MICROBIOLOGICALLY ENRICHED FERTILIZERS ON THE YIELDING OF STRAWBERRY PLANTS IN CONTAINER-BASED CULTIVATION AT DIFFERENT LEVELS OF IRRIGATION

Summary

The experiment was established in the Warsaw University of Life Sciences (SGGW) Experimental Field in Skierniewice in the spring of 2018 in three replications. It was conducted on strawberry plants of the cultivar 'Marmolada' growing in stoneware containers with a diameter of 0.40 m and a height of 1.20 m, containing about 120 litres of podzolic soil with a pH of 6.2 (in KCl). The experiment was conducted in two variants: at 100% hydration and 50% hydration (2x13 fertilizer combinations). The aim of the study was to assess the impact of beneficial microorganisms and innovative mineral fertilizers enriched with them on the fruiting intensity and fruit quality of two-year-old strawberry plants in container-based cultivation, optimally irrigated and subjected to stress of prolonged water deficiency. The method of fertilizing the strawberry plants did not significantly affect the number of inflorescences and flowers. However, the treatments significantly increased the chlorophyll content in the leaves of optimally irrigated plants, especially where they were fertilized with NPK fertilizers and Urea enriched with filamentous fungi, and also the fertilizers Polifoska 6 and Super Fos Dar 40 enriched with beneficial bacteria. With limited water availability, regardless of the type of mineral fertilizer, the microorganisms did not have a significant impact on the characteristics of the strawberry plants grown. Reducing the availability of water to plants by 50% caused a significant decrease in fruit yield and mean fruit weight. The microorganisms, especially the filamentous fungi, helped to limit the impact of water deficiency on the quantity and quality of the obtained fruit crop, especially when compared with the effect of full mineral fertilization. However, the strawberry fruit yield was lower than the yield of optimally irrigated plants by about 30%. Under optimal irrigation, the NPK fertilizer enriched with filamentous fungi significantly increased fruit yield. Similarly, an increase in yield occurred after the application of the fertilizers: Urea in the recommended dose (100%) with the addition of filamentous fungi, and Super Fos Dar 40 in the amount of 60% of the recommended dose enriched with beneficial bacteria. Additional fertilization with the microbiological preparations increased the strawberry fruit yield. Better effects were obtained on the containers with a lower level of irrigation than on those with optimal irrigation.

Key words: *fertilization, beneficial microorganisms, plant growth, irrigation, Fragaria × ananassa*

WPŁYW NAWOZÓW WZBOGACONYCH MIKROBIOLOGICZNIE NA PLONOWANIE TRUSKAWKI W UPRAWIE KONTENEROWEJ PRZY ZRÓŻNICOWANYM POZIOMIE NAWADNIANIA

Streszczenie

Doświadczenie założono na polu doświadczalnym Szkoły Głównej Gospodarstwa Wiejskiego (SGGW) w Skierniewicach wiosną 2018 roku w trzech powtórzeniach. Doświadczenie przeprowadzono na sadzonkach roślin truskawki odmiany 'Marmolada' posadzonych w kamionkowych kontenerach o średnicy 0,40 m i wysokości 1,20 m, wypełnionych 120 litrami gleby bielicowej o pH of 6,2 (w KCl). Doświadczenie prowadzono w dwóch wariantach: 100% nawodnienie i 50% nawodnienia (2 x 13 kombinacji nawozowych). Celem pracy była ocena wpływu pożytecznych mikroorganizmów i innowacyjnych nawozów mineralnych wzbogaconych mikrobiologicznie na intensywność owocowania i jakości owoców dwuletnich roślin truskawki uprawianych w kontenerach, optymalnie nawadnianych i poddanych stresowi suszy. Sposób nawożenia roślin nie miał istotnego wpływu na liczbę kwiatostanów i kwiatów truskawki. Natomiast zabiegi te istotnie zwiększały zawartość chlorofilu w liściach roślin optymalnie nawadnianych, szczególnie tam, gdzie nawożono je nawozami NPK i mocznikiem wzbogaconymi grzybami strzępkowymi oraz nawozami Polifoska 6 i Super Fos Dar 40 wzbogaconymi pożytecznymi bakteriami. Mikroorganizmy przy ograniczonym dostępie wody, niezależnie od rodzaju nawozu mineralnego, nie miały istotnego wpływu na wielkość badanych cech roślin truskawki. Ograniczenie nawodnienia roślin o 50% spowodowało znaczny spadek plonu i masy jednego owocu. Mikroorganizmy, a szczególnie grzyby strzępkowe pozwoliły ograniczyć wpływ niedoboru wody na wielkość i jakość uzyskanego plonu, zwłaszcza w porównaniu do wpływu pełnego nawożenia mineralnego. Plon truskawki był niższy w porównaniu do plonu roślin optymalnie nawadnianych o około 30%. Nawóz NPK wzbogacony grzybami strzępkowymi w tych warunkach zwiększał istotnie jego wielkość. Podobnie po zastosowaniu nawozów: mocznika w zalecanej dawce (100%) z dodatkiem grzybów strzępkowych i nawozu Super Fos Dar 40 w ilości wynoszącej 60% dawki zalecanej, wzbogaconego pożytecznymi bakteriami. Nawożenie preparatami mikrobiologicznymi zwiększyło plon owoców truskawki. Lepszy efekt uzyskano w kontenerach o niższym poziomie nawadniania niż w kontenerach z nawodnieniem optymalnym.

Słowa kluczowe: *nawożenie, pożyteczne mikrorganizmy, wzrost roślin, nawodnienie, Fragaria × ananassa*

1. Introduction

In modern agriculture, and especially in organic plant production, fertilizers with the least negative impact on the environment are being sought [1, 2, 3]. Intensive mineral fertilization, on the one hand, increases the crop yields obtained, while on the other, it increases production costs and contaminates the soil, drinking water and air [4, 5]. One of the proposed solutions to protect the environment and human health is the implementation into agricultural practice of technologies of plant cultivation and fertilization based on natural products: bio-fertilizers, soil conditioners, and microbial inocula [6, 7, 8, 9, 10]. Numerous research studies have shown that the use of fertilizers enriched with beneficial strains of bacteria and fungi increases their effectiveness in plant cultivation [9, 10, 11, 12, 13, 14, 15]. Thanks to these microorganisms, physiological processes in plants are intensified, plant growth and yielding are improved, and plant resistance to biotic and abiotic stress increases [14, 15, 16, 17].

The traditional natural fertilizer, which is farmyard manure, and organic fertilizers such as compost are from year to year increasingly difficult to obtain. One of the innovative solutions tested in recent years is the enrichment of organic fertilizers, e.g. composts and liquid plant growth stimulants, with consortia of beneficial microorganisms [14, 15, 18, 19, 20]. The use of native filamentous and mycorrhizal fungi and beneficial bacterial strains in new bioproducts introduced on the market ensures better adaptation of plants and their survival in adverse environmental conditions [21]. Arbuscular mycorrhizal fungi (AMF), filamentous fungi and beneficial bacteria responsible for the growth and physiological condition of roots can also improve mineral nutrition of plants, and their use in agriculture can lead to a significant reduction in the use of chemicals in plant production [14, 15, 22, 23, 24, 25].

Scientific reports devoted to this problem show that microorganisms, plant extracts and other organic fertilizers can positively affect the growth and yielding of various plant species of high economic importance, including the strawberry [1, 8, 14, 15, 22, 24, 25, 26, 28]. Microorganisms produce favourable effects by decomposing, mobilizing and humifying organic matter, and incorporating its elements into biological processes, as well as by forming and stabilizing the soil environment [18, 19, 29, 30, 32]. A particularly large role in this process is attributed to arbuscular mycorrhizal fungi. They produce and secrete into the soil a stable protein compound – glomalin, which helps in the formation of a crumb texture and increases the stability of the soil structure [33]. These fungi form numerous spores, from which mycelium hyphae develop at different times during vegetation, on the roots of strawberry plants and other crop plants, with the effect of additionally stabilizing the soil, intensively absorbing water, and secreting organic compounds into the soil environment to facilitate dissolution and uptake of mineral compounds that promote plant growth [2, 9, 10, 22, 34].

Many researchers have emphasized that the use of fertilizers enriched with beneficial strains of bacteria and fungi increases their efficiency in plant nutrition [9, 10, 12, 13, 14, 15, 35]. As a result of the activities of microorganisms, the physiological processes in plants are enhanced, so that subsequently their growth and yielding are intensified. Consequently, plants fertilized in this way develop increased resistance to environmental and biotic stresses [14, 15, 16, 17, 36].

The availability of water, as many authors have emphasized, is one of the most important factors affecting the life of crop plants and microorganisms coexisting with them [36, 37]. Many authors have also written about the fact that soil microorganisms, including fungi and bacteria, can reduce drought stress caused by a deficit of water supplied to plants during vegetation [15, 28, 36, 37, 38]. The mechanisms of interaction between crop plants and microorganisms have been the object of numerous studies aimed at understanding them. There are reports providing evidence that they behave differently in an optimally irrigated environment and where there is a persistent or periodic water deficit in the soil [15, 16, 37].

The activity of microorganisms in the rhizosphere, as some authors emphasize, is a factor favourably influencing not only the growth of plants but also their resistance to certain diseases by, among other things, stimulating the internal mechanisms of plant resistance. Direct antagonistic interactions between beneficial microorganisms and pathogens occurring in the soil are also of considerable importance: competition for resources, hyperparasitism, release of biocidal and biostatic compounds into the soil [20, 35, 39, 40]. Rhizosphere bacteria and mycorrhizal and filamentous fungi living on the surface of the roots or near them facilitate the uptake from the soil of macro- and microelements needed for the plants to function properly in various environments, both in those degraded by human activity and also where this phenomenon, harmful to plant life, is not yet present [6, 7, 15, 41].

The development of new, environmentally friendly technologies for growing strawberry plants under the conditions of increasing drought stress requires conducting research on the possibility of using microbiologically enriched mineral fertilizers. Data on the impact of the application of mineral fertilizers enriched with beneficial microorganisms, or on the application of beneficial microorganisms without additional mineral fertilization, on strawberry crop yields under drought stress are scarce. For this reason, in our research, we conducted an assessment of the impact of the application of microbiologically enriched mineral fertilizers and microorganisms applied on their own on the yielding of strawberry plants under drought stress.

The aim of the study was to assess the impact of beneficial microorganisms and innovative mineral fertilizers enriched with them on the fruiting intensity and fruit quality of two-year-old strawberry plants in container-based cultivation, optimally irrigated and subjected to stress of prolonged water deficiency.

Research hypothesis: Innovative microbiologically enriched fertilizers favourably affect the yielding of optimally irrigated strawberry plants and those subjected to drought stress in comparison with the control treatment without fertilization.

2. Materials and methods

The experiment will be carried out for three consecutive years (2018-2020) in the SGGW Experimental Field in Skierniewice (Central Poland, latitude 51.9625 N, longitude 20.1624 E, 128 meters above sea level) on strawberry plants of the cultivar ‘Marmolada’ (synonym ‘Onebor’). Frigo A+ plantlets with a crown diameter of 15-18 mm were planted in early May in stoneware containers with a diameter of 0.40 m and a height of 1.20 m, containing about 120 litres of podzolic soil with a pH of 6.2 (in KCl). The containers with the plants are buried in the ground in an open field. Each of them has three plants growing at a distance of 25 cm from one another. Prior to the experiment, the concentration of macro elements in the soil was as follows: P – 7.5; K – 12.4; Mg – 5.8 mg/100 g, and of micro-elements: B – 2.4; Cu – 4.8; Fe – 862; Mn – 75.5; Na – 4.35; Zn – 3.7 mg/1000 g. The organic matter content of the soil was 1.2%.

Thermal and humidity conditions: the average temperature in the individual months of the 2019 season was: April 10°C, May 13°C, June 22°C, July 19°C, August 20°C, September 14°C, October 10°C. The average relative humidity in those months was – April 50%, May 60%, June 50%, July 60%, August 50%, September 55%, October 60%; sunshine hours - monthly sums: April - 257, May - 194, June - 386, July - 242, August - 274, September - 163, October - 141 (https://meteoblue.com/pl/pogoda/).

The experiment, set up in three replications, consisted of two blocks of plants fertilized equally with mineral fertilizers enriched with beneficial bacteria and filamentous fungi, but under conditions of varied irrigation levels. In one block, plants were optimally drip-irrigated according to the indications of tensiometers, while in the other with only half the amount of water fed in the first block.

The three plants in each stoneware container were fertilized as follows:

1. Control (no fertilization) – unfertilized podzolic soil (composition given above).
2. Standard NPK fertilization (control); soil fertilization. 3 g of Super Fos Dar 40 granulated fertilizer, 12.5 g of potassium salt and 8.8 g of Urea were used for each container in early spring in each year. Urea in the amount of 5 g per container was also used in mid-summer.
3. Beneficial soil fungi were added in the amount of 1.3 g per container, thoroughly mixing them with the soil (without fertilization). The mixture of beneficial soil fungi contained two species: *Aspergillus niger* and *Purpureocillium lilacinum*.
4. Beneficial bacteria were added in the amount of 3.0 g per container, thoroughly mixing them with the soil (without fertilization). The mixture of beneficial bacteria contained three strains of *Bacillus* (*Bacillus* sp., *Bacillus amyloliquefaciens* and *Paenibacillus polymyxa*).
5. Standard NPK – soil fertilized as in point 2, with beneficial soil fungi listed in point 3.
6. Standard NPK – soil fertilized as in point 2, with beneficial bacteria applied to the soil in the containers as in point 4.
7. Polifoska 6 in a 100% dose with three strains of bacteria of the genus *Bacillus*, which had been incorporated into the fertilizer during the production of granules. It was applied at 6.5 g per container. Urea in the amount of 8.8 g was applied in spring, and subsequently in a dose of 5 g in mid-summer. Potassium salt was given in the amount of 8.3 g.
8. Urea in a 100% dose enriched with strains of filamentous fungi of the species and quantitative composition as in point 3. In addition, 12.5 g of potassium salt, 8.8 g of Urea and 3 g of Super Fos Dar 40 fertilizer were added in spring to each container. Urea in the amount of 5 g was also applied in mid-summer.
9. Polifoska 6 in a 100% dose. 26 g of it, 33 g of potassium salt and 30 g of Urea were applied to each container. Urea in the amount of 20 g was also used in the second dose applied in mid-summer.
10. Super Fos Dar 40 in a 100% dose enriched with three strains of *Bacillus* bacteria in the amount of 3.83 g per container. In spring, the soil was fertilized with 12.5g of potassium salt, Super Fos Dar 40 fertilizer in the amount of 3 g, and Urea – in early spring in the amount of 8.8 g, and in a dose of 5 g in the middle of summer.
11. Urea in a 60% dose enriched with strains of filamentous fungi of the species and quantitative composition as in point 3. In addition, 7.5 g of potassium salt and 5 g of Urea, and 1.8 g of Super Fos Dar 40 fertilizer were applied to each container in early spring. Urea in the amount of 5 g was also applied in mid-summer.
12. Polifoska 6 in a 60% dose (3,5 g) enriched with three strains of *Bacillus* bacteria as in point 9. Potassium salt 7.5 g and Urea were applied twice, 4.5 g in spring and again 5 g in mid-summer.
13. Super Fos Dar 40 in a 60% dose (1.75 g) enriched with three strains of *Bacillus* bacteria as in point 11. In spring, 7 g of Super Fos Dar 40 fertilizer 7.5 g of potassium salt, and 5 g of Urea were added to the soil in each container. Urea in the amount of 3 g per container was also used to fertilize the strawberry plants in the middle of summer.

In the first year after planting the strawberry plants, their inflorescences were systematically removed so that the development of fruit would not inhibit plant growth [42]. The effectiveness of the microbiologically enriched fertilizers and the microorganisms added to the soil on their own, as well as of the varied irrigation of the plantation was evaluated based mainly on the number of inflorescences and flowers, fruiting intensity and fruit quality. The intensity of the green colour of the leaves was also determined.

2.1. Assessment of flowering intensity

The number of inflorescences and flowers was counted on five plants from each fertilization treatment.

2.2. Assessment of fruit yield and mean fruit weight

Fruits from each plot were harvested three times at five-day intervals. On each date, the following parameters were determined for each plot:

– the number of fruits and their weight expressed in grams;
– the weight of one fruit (mean fruit weight), expressed in g, calculated by dividing the total weight of fruits harvested from a plot by the total number of them.

2.3. Measurements and observations made

2.3.1. Leaves

The intensity of the green colour of the leaves was determined with a SPAD 502 meter using a sample of 5 leaves taken in the middle of July from two plants in each replication.

2.4. Statistical analysis

The results were statistically analyzed using a one-way analysis of variance with the Tukey test, $\alpha = 0.05$, by means of the statistical program Statistica 13.1. Data not significantly different are marked with the same letters.

2.5. Characteristics of the fertilizer Super Fos Dar 40, Polifoska 6 and Urea

Super Fos Dar 40 belongs to the group of the most concentrated phosphorus fertilizers. It contains 40% P_2O_5 – phosphorus pentoxide soluble in mineral acids; 25% P_2O_5 soluble in neutral citrate and water; 10% CaO – calcium oxide soluble in water, and microelements (Co, Cu, Fe, Mn, Zn), which are a valuable addition derived from natural phosphates that improves the absorption of other ingredients.

Polifoska 6 is a granulated fertilizer containing 6% nitrogen (N) in ammonium form, 20% phosphorus (P_2O_5), 30% potassium (K_2O) in the form of potassium salt, and 7% water-soluble sulphur trioxide (SO_3) in the form of sulphate.

Urea is a granulated fertilizer from the group of nitrogen fertilizers containing 46% N in the amide form.

3. Results

The results of the experiment show that the type of fertilization with optimal (Table 1) and limited (Table 2) irrigation of strawberry plants has no effect on the number of inflorescences and flowers. In contrast, the chlorophyll content in the leaves largely depends on the availability of water to the plants. With limited water availability, the leaves contain less chlorophyll than those of optimally irrigated plants. A significant increase in chlorophyll content is observed especially in the plants fertilized with NPK enriched with filamentous fungi and beneficial bacteria, and in those fertilized with Polifoska 6 at a concentration of 100% enriched with strains of beneficial bacteria at optimal irrigation (Table 1).

The conducted research shows that the bacteria and filamentous fungi introduced into the soil on their own, with optimal (100%) irrigation of plants, had a significant effect on increasing fruit yield in comparison with the control combination (without fertilization) (Table 3).

Table 1. Effect of microbiologically enriched mineral fertilizers on the number of inflorescences, the number of flowers, and the chlorophyll content in the leaves of 'Marmolada' strawberry plants growing under optimal irrigation conditions – 100% of water dose (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2019).
Tab. 1. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na liczbę kwiatostanów, liczbę kwiatów oraz zawartość chlorofilu w liściach roślin truskawki odmiany Marmolada rosnących w optymalnych warunkach nawadniania – 100% dawki wody (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2019 r.).

No	Treatment	Number of inflorescences	Number of flowers	Chlorophyll content in leaves [SPAD]
1.	Control (no fertilization)	6.1 a	37.8 a	34.7 ab
2.	Control NPK (fertilizer combination)	6.2 a	36.0 a	40.4 c-e
3.	Fungal strains (without NPK)	6.8 a	41.1 a	35.1 a-c
4.	Bacterial strains (without NPK)	5.2 a	33.5 a	35.5 a-d
5.	NPK + fungal strains	7.2 a	41.0 a	40.6 de
6.	NPK + bacterial strains	7.2 a	40.6 a	40.8 de
7.	Polifoska 6 100% + bacterial strains	7.2 a	40.9 a	40.9 e
8.	Urea 100% + fungal strains	5.6 a	35.3 a	39.6 b-e
9.	Polifoska 6 100%	6.4 a	33.0 a	37.2 a-e
10.	Super Fos Dar 40 100% + bacterial strains	6.3 a	37.5 a	32.6 a
11.	Urea 60% + fungal strains	5.2 a	35.5 a	37.6 a-e
12.	Polifoska 6 60% + bacterial strains	6.4 a	39.1 a	38.0 a-e
13.	Super Fos Dar 40 60% + bacterial strains	5.9 a	34.2 a	38.5 b-e

* Means marked with the same letters in a column do not differ significantly at $\alpha = 0.05$.

Source: own study / Źródło: opracowanie własne

Table 2. Effect of microbiologically enriched mineral fertilizers on the number of inflorescences, the number of flowers, and the chlorophyll content in the leaves of 'Marmolada' strawberry plants growing under drought stress – 50% of water dose (container-based experiment, Experimental Field, SGGW, Skierniewice, 2019)
Tab. 2. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na liczbę kwiatostanów, liczbę kwiatów oraz zawartość chlorofilu w liściach roślin truskawki odmiany 'Marmolada' rosnących w warunkach stresu suszy – 50% dawki wody (doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2019 r.)

No	Treatment	Number of inflorescences	Number of flowers	Chlorophyll content in leaves [SPAD]
1.	Control (no fertilization)	5.2 a	29.7 a	38.8 a
2.	Control NPK (fertilizer combination)	4.7 a	31.2 a	36.4 a
3.	Fungal strains (without NPK)	5.4 a	31.5 a	31.9 a
4.	Bacterial strains (without NPK)	4.6 a	24.8 a	37.7 a
5.	NPK + fungal strains	5.0 a	33.6 a	38.2 a
6.	NPK + bacterial strains	5.9 a	34.1 a	39.3 a
7.	Polifoska 6 100% + bacterial strains	5.1 a	30.4 a	35.6 a
8.	Urea 100% + fungal strains	5.1 a	30.7 a	39.7 a
9.	Polifoska 6 100%	6.2 a	38.2 a	40.6 a
10.	Super Fos Dar 40 100% + bacterial strains	4.4 a	27.6 a	31.8 a
11.	Urea 60% + fungal strains	4.6 a	24.4 a	39.0 a
12.	Polifoska 6 60% + bacterial strains	4.4 a	28.9 a	39.2 a
13.	Super Fos Dar 40 60% + bacterial strains	5.0 a	29.7 a	38.2 a

* Means marked with the same letters in a column do not differ significantly at $\alpha = 0.05$.

Source: own study / Źródło: opracowanie własne

The yield improved after using NPK enriched with bacteria, and Urea at 100% and 60% enriched with filamentous fungi, as well as Polifoska 6 and Super Fos Dar 40 fertilizers at 60% enriched with beneficial bacteria (Table 3). In terms of fruit size, however, a significant impact, with optimal (100%) irrigation, occurred only as a result of fertilizing strawberry plants with the NPK fertilizer enriched with beneficial bacteria. The mean fruit weight ranged from 10.6 g to 14.1 g, depending on the type of fertilization used. The largest fruits were produced by the plants fertilized with the NPK fertilizer enriched with beneficial bacteria, and the smallest ones in the control combination (Table 3).

With optimal irrigation, the yield of strawberry fruit expressed as a percentage in relation to the control combination increased in all the fertilization combinations. The highest yield was obtained from the plants fertilized with NPK combined with beneficial bacteria and also from the plants fertilized with the bacteria on their own (Table 3). Urea at 100% and 60% enriched with a consortium of filamentous fungi and the fertilizers Polifoska 6 at 60% and Super Fos Dar 40 at 60% enriched with beneficial bacteria also produced positive effects on fruiting (Table 3).

In terms of increasing the mean fruit weight, the fertilizers NPK, Polifoska 6 at 100% and 60%, and Urea at 100% and 60% enriched with filamentous fungi had a considerable impact. The most effective was the fertilization of plants with the NPK fertilizer enriched with beneficial bacteria (Table 3).

With limited irrigation of plants (50% water), a significant increase in fruit yield was observed after fertilizing the plants with NPK together with filamentous fungi and Super Fos Dar 40 at 60% enriched with a consortium of beneficial bacteria of the genus *Bacillus* (Table 4).

The type of fertilization had no significant effect on mean fruit weight. Fruits of the strawberry plants growing under water deficit were small and their weight ranged from 7.0 to 11.7 g (Table 4).

With limited availability of water to strawberry plants, the application of NPK without microorganisms resulted in a decrease in fruit yield and mean fruit weight. Moreover, under these conditions, the application of Polifoska 6 at 100% together with bacteria contributed to a reduction in fruit weight (Table 4). In the other combinations, under the conditions of limited water availability, an increase in the yield and weight of strawberry fruit was found. The highest yield was obtained after the application of Urea at 100% enriched with beneficial fungi, NPK fertilization together with beneficial fungi, and after the application of Super Fos Dar 40 fertilizer at 60% combined with beneficial bacteria (Table 4).

The study shows that in comparison with optimal irrigation the limited supply of water to strawberry plants reduces the yield of strawberry fruit by from 30% to almost 60%, and the mean fruit weight by from about 10% to almost 40%, depending on the fertilization treatment (Table 5). The microorganisms, especially the filamentous fungi, help to some extent to limit the impact of persistent water deficiency on the quantity and quality of the obtained fruit crop, especially when compared to the effect of full mineral fertilization applied under stress conditions, in which there is a clear decrease in the size of the crop. The application of fertilizers such as Urea at a concentration of 100% and also Polifoska 6 and Super Fos Dar 40 at a concentration of 60% also makes it possible to reduce the negative effects of water deficiency (Table 5).

4. Discussion

Many authors emphasize that intensive fertilization of plants with mineral fertilizers degrades the natural environment, does not always have a beneficial effect on plant growth and fruiting, and often negatively affects crop quality and storage life. Therefore, methods are being sought to reduce the negative impact of agriculture on the environment by partially replacing mineral fertilizers with products of natural origin. A real opportunity in this respect is presented by natural and organic fertilizers as well as selected soil and endophytic microorganisms, including filamentous and mycorrhizal fungi and beneficial bacteria [1, 2, 3, 4, 5, 6, 7, 8, 9].

Table 3. Effect of microbiologically enriched mineral fertilizers on fruit yield and mean fruit weight of ‘Marmolada’ strawberry plants growing under optimal irrigation conditions – 100% of water dose, also expressed as a percentage in relation to the control combination (container-based experiment, Experimental Field, SGGW, Skierniewice, 2019)

Tab. 3. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na plon i masę owoców roślin truskawki odmiany ‘Marmolada’ rosnących w optymalnych warunkach nawadniania - 100% dawki wody oraz wyrażony w procentach w odniesieniu do kombinacji kontrolnej (doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2019 r.)

No	Treatment	Yield [g]	Yield [%]	Mean fruit weight [g]	Mean fruit weight [%]
1.	Control (no fertilization)	635.0 a	100.0	10.5 a	100.0
2.	Control NPK (fertilizer combination)	903.0 ab	142.2	11.3 ab	107.6
3.	Fungal strains (without NPK)	926.3 b	145.9	10.6 a	101.0
4.	Bacterial strains (without NPK)	982.0 b	154.6	12.28 ab	117.0
5.	NPK + fungal strains	893.3 ab	136.0	11.41 ab	108.7
6.	NPK + bacterial strains	1061.3 b	167.1	14.1 b	134.3
7.	Polifoska 6 100% + bacterial strains	857.0 ab	135.0	12.5 ab	119.0
8.	Urea 100% + fungal strains	934.3 b	147.1	12.7 ab	120.9
9.	Polifoska 6 100%	820.0 ab	136.4	11.8 ab	112.4
10.	Super Fos Dar 40 100% + bacterial strains	808.3 ab	127.3	11.5 ab	109.5
11.	Urea 60% + fungal strains	950.0 b	149.6	13.2 ab	125.7
12.	Polifoska 6 60% + bacterial strains	965.0 b	152.0	13.5 ab	128.6
13.	Super Fos Dar 40 60% + bacterial strains	923.3 b	145.0	11.7 ab	111.0

* Means marked with the same letters in a column do not differ significantly at α = 0.05.

Source: own study / Źródło: opracowanie własne

Table 4. Effect of microbiologically enriched mineral fertilizers on fruit yield and mean fruit weight of 'Marmolada' strawberry plants growing under drought stress – 50% of water dose, also expressed as a percentage in relation to the control combination (control-based experiment, SGGW, Skierniewice, 2019)

Tab. 4. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na plon i masę owoców roślin truskawki odmiany 'Marmolada' rosnących w warunkach stresu suszy – 50% dawki wody oraz wyrażony w procentach w odniesieniu do kombinacji kontrolnej (doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2019 r.)

No	Treatment	Yield [g]	Yield [%]	Mean fruit weight [g]	Mean fruit weight [%]
1.	Control (no fertilization)	412.3 a	100.0	8.0 ab	100.0
2.	Control NPK (fertilizer combination)	396.0 a	89.5	7.0 a	87.5
3.	Fungal strains (without NPK)	536.3 a-c	130.0	9.5 ab	118.8
4.	Bacterial strains (without NPK)	470.0 ab	114.0	8.2 ab	102.5
5.	NPK + fungal strains	615.6 bc	149.3	9.9 ab	123.8
6.	NPK + bacterial strains	521.6 a-c	126.5	9.3 ab	116.3
7.	Polifoska 6 100% + bacterial strains	556.6 a-c	135.0	9.7 ab	121.3
8.	Urea 100% + fungal strains	655.0 c	158.9	11.7 b	146.3
9.	Polifoska 6 100%	504.0 ab	122.0	7.2 a	90.0
10.	Super Fos Dar 40 100% + bacterial strains	524.3 a-c	127.2	10.0 ab	125.0
11.	Urea 60% + fungal strains	499.6 a-c	121.2	10.5 ab	131.3
12.	Polifoska 6 60% + bacterial strains	562.0 a-c	136.3	8.2 ab	103.0
13.	Super Fos Dar 40 60% + bacterial strains	593.0 bc	143.8	9.6 ab	120.0

* Means marked with the same letters in a column do not differ significantly at α = 0.05.

Source: own study / Źródło: opracowanie własne

Table 5. Fruit yield and mean fruit weight of 'Marmolada' strawberry plants growing under conditions of limited irrigation (50% of water dose) and fertilized with microbiologically enriched mineral fertilizers, expressed as a percentage in relation to the fruit yield and mean fruit weight of optimally irrigated plants (container-based experiment, Experimental Field, SGGW, Skierniewice, 2019)

Tab. 5. Wielkość plonu i masy owocu truskawki odmiany 'Marmolada' roślin rosnących w warunkach ograniczonego nawadniania (50% dawki wody) i nawożonych nawozami mineralnymi wzbogaconymi mikrobiologicznie wyrażony w procentach w odniesieniu do wielkości plonu i owocu roślin nawadnianych optymalnie (doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2019 r.)

No	Treatment	Yield [%]	Mean fruit weight [%]
1.	Control (no fertilization)	64.9	76.0
2.	Control NPK (fertilizer combination)	43.9	62.0
3.	Fungal strains (without NPK)	57.9	90.0
4.	Bacterial strains (without NPK)	47.9	66.7
5.	NPK + fungal strains	71.3	87.0
6.	NPK + bacterial strains	49.1	66.0
7.	Polifoska 6 100% + bacterial strains	65.0	77.6
8.	Urea 100% + fungal strains	70.0	92.0
9.	Polifoska 6 100%	56.8	85.0
10.	Super Fos Dar 40 100% + bacterial strains	64.9	87.0
11.	Urea 60% + fungal strains	53.0	80.0
12.	Polifoska 6 60% + bacterial strains	58.2	61.0
13.	Super Fos Dar 40 60% + bacterial strains	64.2	82.0

* Means marked with the same letters in a column do not differ significantly at α = 0.05.

Source: own study / Źródło: opracowanie własne

Numerous research studies have shown that the use of fertilizers enriched with beneficial bacterial and fungal strains increases their effectiveness in plant cultivation [9, 12, 13, 14, 15, 35]. Due to the presence of beneficial microorganisms in the soil environment, the physiological processes in plants intensify, their growth and yielding improve, and their resistance to abiotic and biotic stress increases [14, 15, 16, 17, 21, 43].

In our study, with optimal irrigation of strawberry plants, it was evident that in the combinations where the plants were treated with filamentous fungi and beneficial bacteria alone, and with mineral fertilizers enriched with them, the fruit yields obtained, although similar, were better than in the unfertilized control. Einizadeh and Shokouhian [43] had obtained better plant growth parameters, increased fruit yield and better fruit quality parameters (fruit size and weight) in the strawberry cultivar 'Paros' after treatment with a solution of a commercial preparation of the ‘Effective Microorganisms’ type. The best results, in comparison with the control, were obtained with a 2% solution of the preparation, whereas in the case of a 3% solution, the yields were slightly lower than when a 2% solution was used. However, the obtained fruits had the highest soluble solids content, but this result was not statistically significant. Application of a 1% solution gave only slight increases in growth and yield parameters relative to the control.

Other authors have also obtained results indicating the benefits of using microorganisms in plant cultivation [9, 12, 13, 14, 15, 35, 43].

Water, as many authors emphasize, plays a very important role in the life of plants [14, 15, 16, 17, 36, 37, 44]. Water stress negatively affects both plant growth and fruiting. The results of our study indicate that reducing the availability of water to plants by half causes a decrease in strawberry fruit yield by from 30% to 60%, depending on the type of fertilization. A positive role of filamentous fungi and beneficial bacteria in reducing the effects of water stress has been observed. Full fertilization with NPK and with Urea at a concentration of 100%, both enriched with filamentous fungi, and fertilization with Super Fos Dar 40 at a concentration of 60% enriched with beneficial bacteria limited fruit yield losses caused by water deficiency. However, these treatments were not able to bring the yield up to the level obtained with the optimally irrigated plants.

Studies by other authors have also demonstrated a positive effect of beneficial microorganisms on increasing the tolerance of strawberry plants to drought stress. Erdogan et al. [45] had observed that application of N_2-fixing and P-solubilizing bacteria increased plant growth and yielding of strawberry plants. In that study, the application of bacteria from the genera *Paenibacillus*, *Pseudomonas* and *Rhodococcus* increased the activity of antioxidant enzymes, phytohormones (GA, SA and IAA), and the amounts of N, P, K, Ca, Fe, Mn, Zn and Cu.

Beneficial microorganisms that colonize the rhizosphere of plants have a positive effect on the growth of plants growing under drought stress [44]. Increased drought tolerance of plants, induced by beneficial microorganisms, results from their properties, such as the production of phytohormones (abscisic acid, gibberellic acid, cytokinins and indole-3-acetic acid), the production of ACC deaminase, which reduces the level of ethylene in the roots, the production of exopolysaccharides [46, 47, 48, 49, 50]. The results obtained in this study, and those of other authors, indicate the significant role of beneficial microorganisms in the cultivation of strawberry under drought stress conditions.

In other studies, a positive effect of beneficial microorganisms on the number of flowers of strawberry plants has been observed. Fertilizing strawberry plants with vermicompost enriched with *Azotobacter* bacteria and arbuscular mycorrhizal fungi increased the number of flowers in comparison with control plants [51]. Application of a consortium of *Pseudomonas* spp. beneficial bacteria and AM fungi (*Rhizophagus intraradices*, *Glomus aggregatum*, *Glomus viscosum*, *Claroideoglomus etunicatum* and *Claroideoglomus claroideum*) increased the number of flowers of strawberry plants under conditions of conventional fertilization reduced to 70% [52]. The fact that no influence of beneficial microorganisms on the number of flowers was observed in our study could have probably been due to the properties of the strains of the microorganisms used, or because of a sufficient supply of minerals to the plants.

5. Conclusions

1. Additional fertilization with the microbiological preparations increased the strawberry fruit yield. Better effects were obtained on the plots with a lower level of irrigation than on those with optimal irrigation.
2. The bacterial preparations worked better with optimal irrigation, while the fungal preparations did so under drought conditions.
3. On the plots with economical irrigation (50% of needs), the microbiological preparations worked better than NPK fertilization alone, and with optimal irrigation the yield-enhancing effect was the same as that of NPK fertilization.
4. Reducing the dose of Polifoska and Super Fos Dar 40 to 60% of the optimal dose resulted in an increase in strawberry fruit yield in comparison with full fertilization. This indicates that the proposed NPK doses, combined with the addition of microbiological preparations, were too high.
5. The results indicate that, when applying the microbiological preparations used in this study, NPK fertilization can be considerably reduced, which is beneficial for economic and environmental reasons.

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